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NEW DEVICE TO ADJUST ON LOAD THE VOLTAGE LEVEL AT POWER TRANSFORMERS

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ABSTRACT
Many industrial activities and also our nowadays life utilities such as lighting system or different electronic devices request a constant voltage level or a little variation between certain admissible limits. It is a real problem when it takes into account that more and more customers use PCs or network system PCs because it is well known that these kind of systems need a constant voltage supply level.
With this aim it was achieved a new device with the possibility to make on-line step voltage regulation and/or continuous voltage adjustment. The proposed voltage regulator maintains the constant voltage on the load under the conditions of input voltage and/or load current variations.

KEY WORDS
voltage regulation, on load tap changers, power transformers

1. Introduction

The purpose of distribution system voltage control is to compensate for load variations and events in the feeding network so that a suitable voltage profile is maintained at every load bus. Power transformers equipped with On-Load Tap-Changers (OLTCs) have been main components of electrical networks and industrial application for nearly 80 years. The OLTC allows voltage regulation and/or phase shifting by varying the transformer ratio under load without interruption. From the beginning of Tap-Changer development, two switching principles have been used for the load transfer operation, the highspeed resistor type OLTC and the reactor type OLTC. Over the decades both principles have been developed into reliable transformer components available in a broad range of current and voltage applications to cover the needs of today's network and industrial process transformers [1, 2].
The OLTC changes the ratio of a transformer by adding turns to or subtracting turns from either the primary or the secondary winding. Therefore, the transformer is equipped with a so called regulating or tap winding which is connected to the OLTC. Simple changing of taps during energized condition is unacceptable due to momentary loss of system load during the switching operation. Therefore the "make before break contact concept", is the basic design for all OLTCs. The transition impedance in form of a resistor or reactor consists of one or more units that are bridging adjacent taps for the purpose of transferring load from one tap to the other without interruption or appreciable change in the load current. At the same time they are limiting the circulating current for the period when both taps are used. Normally, reactor type OLTCs use the bridging position as a service position and, therefore, the reactor is designed for continuous loading. The voltage between the mentioned taps is the step voltage, it normally lies between 0.8 % and 2.5 % of the rated voltage of the transformer. The main components of an OLTC are contact systems for make and break currents as well as carrying currents, transition impedances, gearings, spring energy accumulators and a drive mechanism.
Along with the increase in demand for electrical energy in metropolitan areas, the necessity for installing transformers in buildings creates a need for regulating transformers with reduced fire hazards. In addition to this and with respect to the prevention of water pollution, those regulating transformers are preferable that do not require conventional mineral oil as insulating or switching medium. Apart from gas-immersed transformers, mainly used in Japan, drytype transformers, and transformers with alternative insulating fluids meet these requirements, which are increasingly asked for. For these kind of regulating transformers, the conventional tapchangers are little suitable, because the use of mineral oil as switching medium is – for the reasons mentioned above – not desirable and would moreover require technically complex and expensive overall solutions, [3 - 8]. Furthermore worldwide deregulation in the electric industry is still of concern. As part of this market, mechanisms have been encouraged to price transmission services and encourage both generation and transmission investment. In consequence, increased cost pressure on utilities as well as for the industry has led to increased performance expectations on the transformer equipment and OLTC, in particular:

- long-term uninterrupted availability of the regulating transformer, i. e. extension of the maintenance intervals and reduction of the maintenance work;
- low failure rate;
- reduction of the operating costs.

For all above mentioned new application fields and increased performance expectations a new common switching technology was asked for. Various approaches with solid state technology are being discussed since the eighties [9, 10], like thyristor-assisted tap changers and solid state tap changers, but only a few applications have been realized. Thyristor-assisted tap changers, [11, 12] use thyristors to take the on-load current whilst the main contacts change over from one tap to the next. This prevents arcing on the main contacts and can lead to a longer service life between maintenance activities. The disadvantage is that these tap changers are more complex and require a low voltage power supply for the thyristor circuitry. They also can be more costly. Solid state tap changers, [13 - 15] are a relatively recent development which use thyristors both to switch the load current and to pass the load current in the steady state. Their disadvantage is that all of the non-conducting thyristors connected to the unselected taps still dissipate power due to their leakage current. This power can add up to a few kilowatts which has to be removed as heat and leads to a reduction in the overall efficiency of the transformer. They are therefore only employed on smaller power transformers.

2. The new device principles

The simplified block diagram of voltage control system of the new device is shown below, Fig.1. The voltage supply from the power plant is used like primary voltage U_1, for the power transformer and then its secondary voltage U_2, is regulated by the new device in order to provide the output voltage U_{2a}, according to the customers' requests.
The input data of secondary voltage U_2 of the power transformer, the voltage across the load, U_{2a}, and the load current, I_l, are permanently analysed by control unit using suitable voltage and current transducers.

When the output voltage value is out of range level, then the control unit will provide the proper control signals U_c, to regulate the voltage value. Finally, the adjusted voltage U_{2a}, must be between admissible limits. The voltage and current acquisition, analysis and output control signals are achieved using a digital relay programmed with a specific software.
The new device includes an auxiliary transformer AT, Fig.2, which provides an additional voltage that can be summed or subtracted (depending on magnetic flux sense), from secondary voltage U_2 of the power transformer PT, using a proper logic sequence ON/OFF for the power electronic switches SC, VC1 and VC2. The power switches are made with triacs. Hence, the mechanical contacts of nowadays tap-changers have been replaced with electronic switches. To avoid shortcircuits on the primary winding of the auxiliary transformer AT, a suitable circuit breaker CB, has been mounted. The control signals for the power switches come from the digital relay DR. This includes comparators, analog and digital inputs, analog and digital outputs, has the possibility to set thresholds values for input signals and allow to introduce low variations for the output voltages.
The signals of secondary voltage U_2 of the power transformer PT, the voltage U_z across the load Z, and the load current I_s, are obtained using the step-down transformers VT1 and VT2, like voltage transducers and the current transformer CT. These signals mean analog inputs (AI1, AI2 and AI3) for the digital relay DR. After input signal processing, the digital outputs (DO1, DO2 and DO3) command the electronic switches (SC, VC1 and VC2) and the analog output AO, controls the variable inductance VI.
The new device has the possibility to make a step and/or continuous voltage adjustment. The step voltage variation is achieved when the power switches SC, VC1 and VC2, include or shortcircuited different number of turns from the primary of the auxiliary transformer AT. Therefore, there is a step regulation of the voltage across the secondary of the auxiliary transformer AT. The continuous voltage regulation is done using a controlled variable inductance VI, based on magnetic amplifier principle.

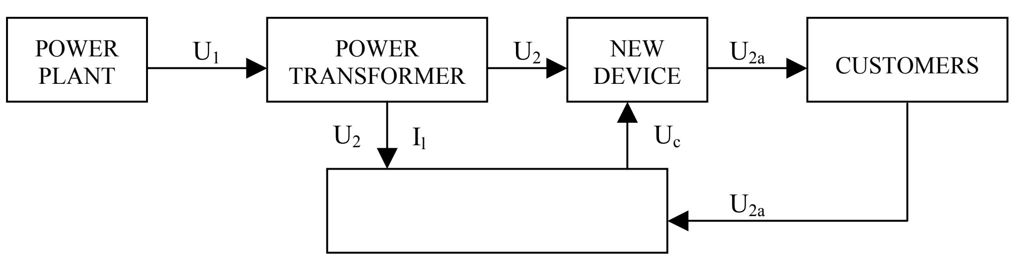

Fig. 1 Block diagram of the voltage control system.

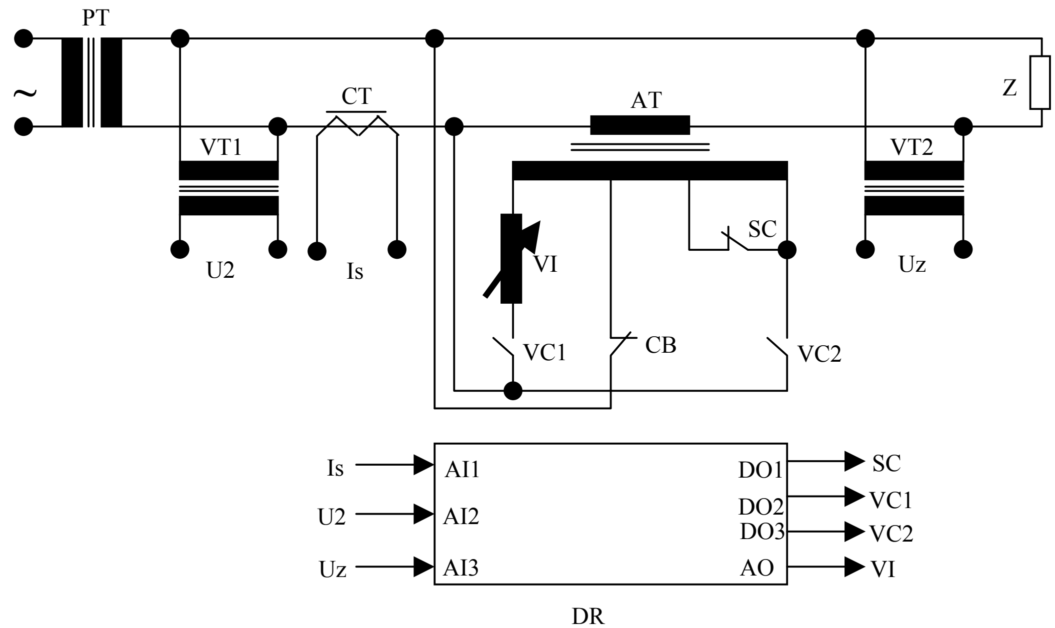

Fig. 2 Block diagram of the new device.

The control signal provided by the analog output of the digital relay, will vary the impedance of the variable inductance VI. Hence, the primary voltage of the auxiliary transformer AT, will be regulated and the secondary voltage across the AT, will have a continuous variation.
For instance, when the secondary voltage goes under an admissible value, the switch SC opens and the VC1 turns on. Therefore, the output voltage is increased with a step value because of the auxiliary transformer AT. If the consumer needs a continuous voltage regulation, then the variable inductance works being controlled by the digital relay DR. But, when the secondary voltage goes up to an admissible value, the switch VC2 turns on, the SC being opened. Hence, the output voltage is decreased with a step value because of the same auxiliary transformer AT. At normal operating conditions, the switches VC1 and VC2 are opened and SC is closed. Therefore, a part of auxiliary transformer primary winding is shortcircuited, and the supplementary voltage has a very small value, around 1V.

3. New device construction

Starting with the input data (secondary rated current: 57.7A, admissible limits of the voltage level: ±10% of rated voltage, rated power: 40kVA, etc.) of the power transformer to be equipped with the new device, it has been calculated the dimensions of magnetic circuit and windings of the auxiliary transformer and controlled variable inductance, taking into account the criterion of minimum power loss. It was adopted a toroidal transformer construction with the following parameters for the auxiliary transformer:

- rated power: 1kVA;
- primary winding: 510 turns with taps at 240 and 310 turns (copper wire diameter: 2mm);
- secondary winding: 28 turns (copper wire diameter: 5 x 1.9mm);
- magnetic circuit dimensions: 200 x 100 x 50 (outside diameter x inside diameter x high) [mm].

The variable inductance has been built using two identical toroidal magnetic cores and only one controlled winding based on magnetic amplifier principle, with the following parameters:

- rated power: 800VA;
- two primary windings: 240 turns (copper wire diameter: 1.4mm);
- controlled winding: 200 turns (copper wire diameter: 1.55mm);
- magnetic circuit dimensions: 200 x 100 x 20 (outside diameter x inside diameter x high) [mm].

In order to provide a proper control signals for driver circuits of power electronic switches and to variable inductive reactance, a digital relay type EASY 822-DC-TC series has been chosen. Using the design of power electronic modules it has built the assembly of solid-state switches with triacs mounted on an adequate heatsink. A power unit was built in order to supply with suitable voltage level the solid-state switches and digital relays.
Like a final result, the prototype has been mounted into a 19 inch metal cabinet and has the following component parts, Fig.3: 1- power circuit for step voltage adjusting and current transformers; 2- variable inductances for continuous voltage adjusting; 3- power supply block and voltage transducers; 4- control unit; 5- power electronic assemblies; 6- circuit breakers; 7- terminals block.

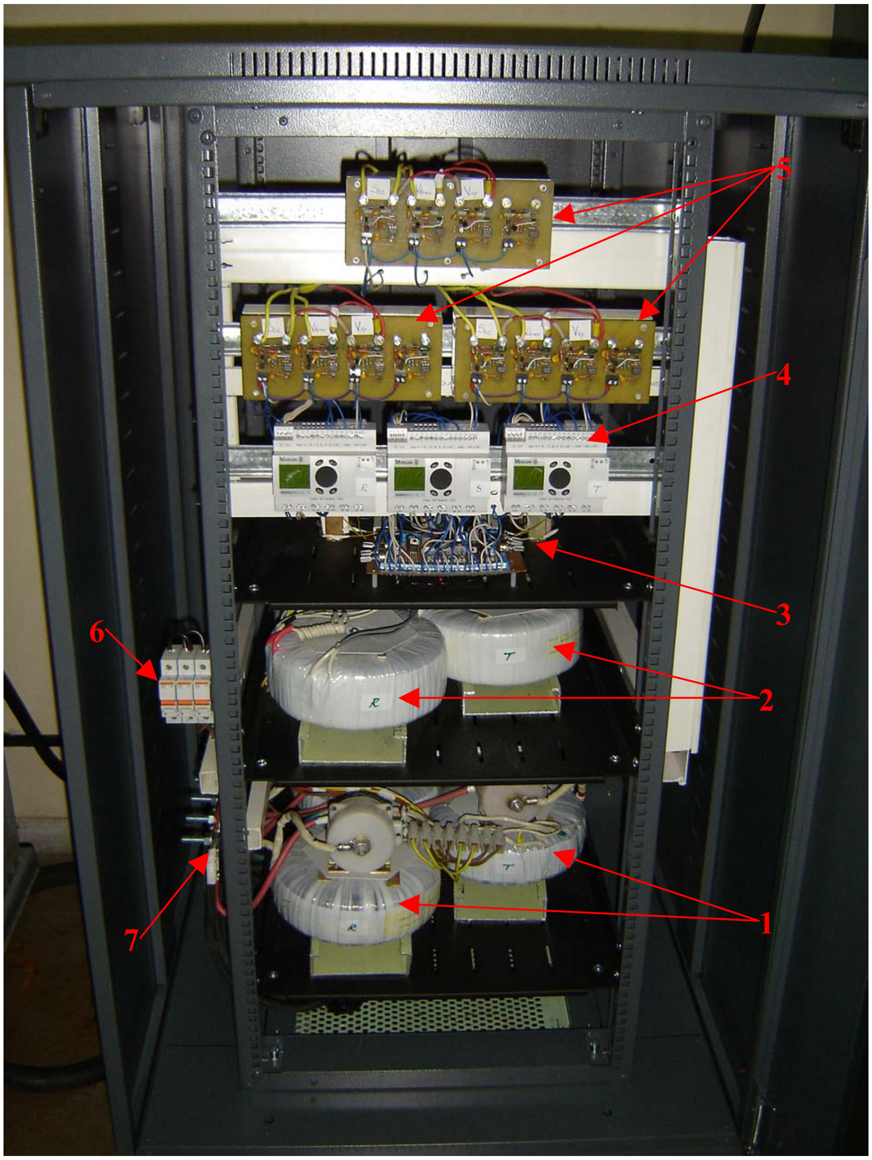

Fig. 3 The prototype (cabinet with opened door).

Some experimental tests have been done using a variable resistive load with a maximum value of 21Ω and a minimum by 3.8Ω. The waveforms of the output voltage at secondary voltage variations are shown in Fig.4 and Fig.5. In the case when the secondary voltage goes down, Fig.4, there is a minimum voltage threshold of $198V_{rms}$, after that the device operates and add a step voltage in order to maintain the voltage level between admissible limits. A rated secondary voltage of $220V_{rms}$ and admissible limits of the voltage level of ±10% (198V and 242V, respectively) have been considered. The same situation applies when the voltage goes up, Fig.5, and the voltage regulator device acts when the maximum voltage threshold of $242V_{rms}$ is reached. From these recorded waveforms it can notice in both cases that the new device restores the output voltage between admissible limits in less than 200ms.

4. Conclusion

The research project brings some contributions in the field of voltage regulation devices, such as:

- the voltage level at customers is adjusted between admissible limits using a modular device with a simplified mechanical and electrical construction;
- the possibility to break off one or more secondary power transformer phases is eliminated;
- improving the operation safety;

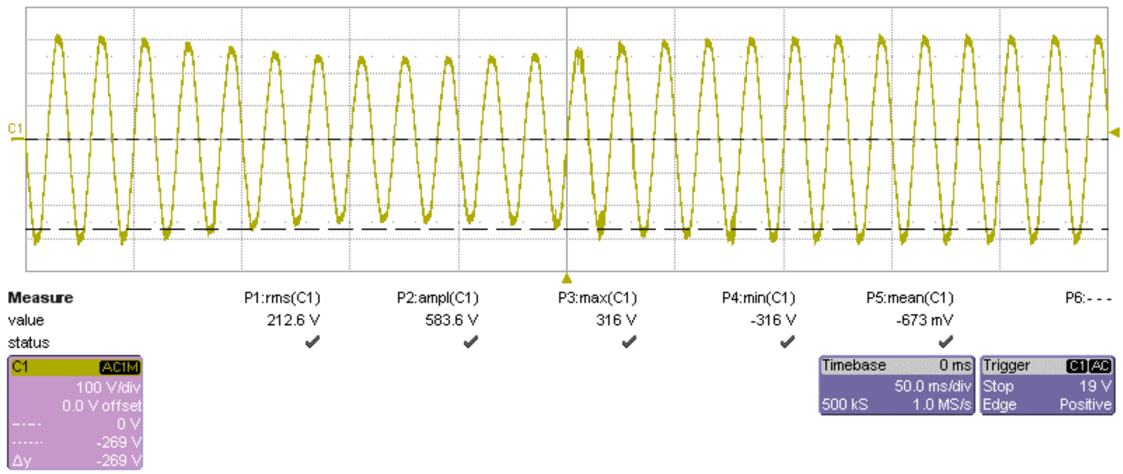

Fig. 4 The output voltage waveform in the case when secondary voltage goes down.

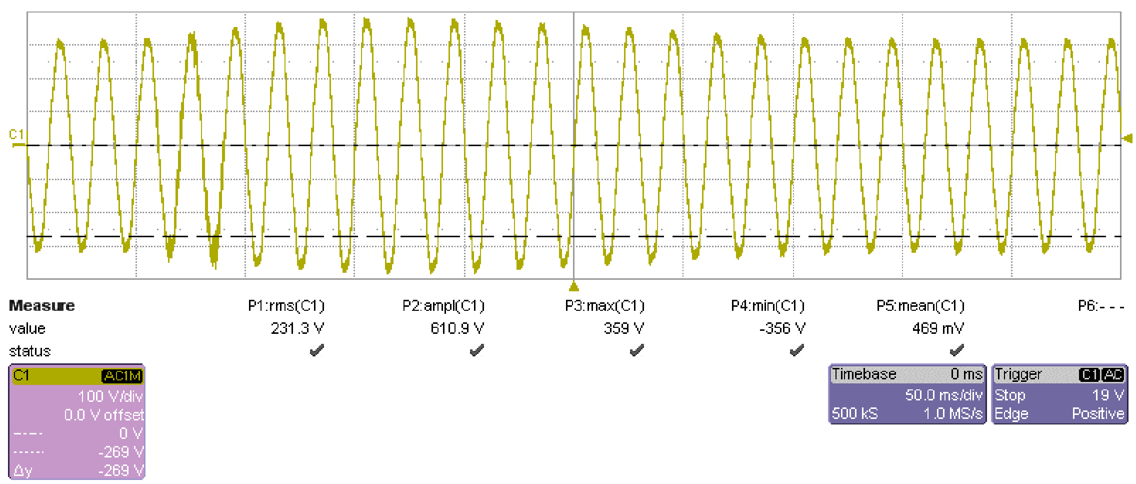

Fig. 5 The output voltage waveform in the case when secondary voltage goes up.

- quick and easy maintenance;
- step and continuous voltage adjusting;
- on-line device control;
- the modular construction of the new device allow an improved flexibility and adaptation to operating conditions and especially to insulated villages.

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References

[1] G. Spence & A.C. Hall, On-load tap-changers current experience and future development: Users experience and perspective, *IEE European Seminar `On-Load Tapchangers: Current Experience and Future Developments'*, 1995, 1/1-7.

[2] G. Dawei, A novel thyristor assisted diverter switch for on load transformer tap changer, *IEEE/PES Transmission and Distribution Conference and Exhibition*, 2002, 297-300.

[3] M.H. Abdel-Rahman, F.M.H. Youssef, & A.A. Saber, New static var compensator control strategy and coordination with under-load tap changer, *IEEE Transactions on Power Delivery*, *21*(3), 2006, 1630-1635.

[4] H. U. Schellhase, R.G. Pollock, A.S. Rao, E.C. Korolenko, & B. Ward, Load tap changers: investigations of contacts, contact wear and contact coking, *Electrical*

Contacts, Proceedings of the Forty-Eighth IEEE Holm Conference on, 2002, 259 – 272.
[5] A.G. Kay, The monitoring and protection of on load tap changers, *IEE Colloquium on Condition Monitoring of Large Machines and Power Transformers*, 1997, 5/1-9.
[6] H.J.A. Martins, J.A. Duque, W. Cerqueira, L.A. Domingues, J.A. Chaves, & M. Braga, Failures/solutions in on-load tap-changers, 145 kV, *Conference Record of IEEE International Symposium on Electrical Insulation*, 1998, 43-46.
[7] M.A. Redfern & W.R.C. Handley, Duty based maintenance for on-load transformer tap changers, *2001 Power Engineering Society Summer Meeting. Conference Proceedings*, 2001, 1824-1829.
[8] G. Dawei, L. Qingchun & L. Jishou, A new scheme for on-load tap-changer of transformers, *Power System Technology, Proceedings. PowerCon*, 2002, 1016 - 1020.
[9] J. Faiz & B. Siahkolah, Differences between conventional and electronic tap-changers and modifications of controller, *IEEE Transactions on Power Delivery*, *21*(3), 2006, 1342-1349.
[10] Li Xiaoming, Liao Qingfen, Yin Xianggen & Xie Jianghui, A new on-load tap changing system with power electronic elements for power transformers, *PowerCon 2002. 2002 International Conference on Power System Technology Proceedings*, 2002, 556-559.
[11] D.A. Peck, On-load tap-changers current experience and future developments. Principles and resulting benefits of separate tank (external) tap-changers, *IEE European Seminar `On-Load Tapchangers: Current Experience and Future Developments'*, 1995, 3/1-9.
[12] O. Demirci, D.A. Torrey, R.C. Degeneff, F.K. Schaeffer & R.H. Frazer, A new approach to solid-state on-load tap changers, *Proceedings of the American Power Conference. 58th Annual Meeting 1996. Technology for Competition and Globalization*, 1996, 957-962.
[13] R.C. Degeneff, New concept for a solid-state on-load tap changers, *IEE Conference Publication*, *Contributions*, 1997, 1.7.1-1.7.4.
[14] J. Vithayathil, M. Arunachalam, A.-A. Edris, B. Ekehov, Y. Fu, H. Henning, M. Lessmann-Mieske Mohaddes, J. Pavelka, A. Phadke, K. Sadek, R. Shuttleworth & C. Taylor, Thyristor controlled voltage regulators. Part II. Static on-load transformer tap changers, *Electra*, 213, 2004, 40-51.
[15] J. Faiz & H. Javidnia, Fast response solid-state on load transformers tap-changer, *Eighth International Conference on Power Electronics and Variable Speed Drives*, 2000, 355-359.